Development and Manufacture of Cost Effective Composite Drill Pipe

2002 Annual Technical Progress Report

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Report Issue Date: September 20, 2002

DOE Cooperative Agreement No: DE-FC26-99FT40262

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DISCLAIMER

ABSTRACT

This technical report presents the engineering research and data accomplishments that have transpired to date in support of the development of Cost Effective Composite Drill Pipe (CDP). The report reiterates the presentation made to DOE/NETL in Morgantown, WV on August 1st, 2002 with the addition of accomplishments made from that time forward until the issue date. The following have been accomplished and are reported in detail herein:

- Specifications for both 5-1/2" and 1-5/8" composite drill pipe have been finalized.
- Full scale testing of Short Radius (SR) CDP has been conducted.
- Successful demonstration of metal to composite interface (MCI) connection.
- Preparations for full scale manufacturing of ER/DW CDP have begun.
- Manufacturing facility rearranged to accommodate CDP process flow through plant.
- Arrangements to have the 3 3/8" CDP used in 4 separate drilling applications in Oman, Oklahoma, and Texas.

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1.0 Executive Summary

The objective of this contract is to develop and demonstrate "cost effective" Composite Drill Pipe (CDP). This drill pipe will weigh less than half of its steel counter part. The resultant weight reduction will provide enabling technology to drastically increase the lateral distance which can be reached from an offshore drilling platform and the depth of water in which drilling and production operations can be carried out. Further, composite drill pipe has the capability to carry real time signal and power transmission within the pipe walls. CDP can also accommodate much shorter drilling radius than is possible with metal drill pipe.

As secondary benefits the lighter weight drill pipe can increase the storage capability of floating off shore drilling platforms and provide substantial operational cost savings. It is anticipated that commercial CDP will be available in 2003 at 2 to 5 times the cost of comparable steel pipe.

Specifications have been prepared, reviewed and finalized for both 3 3/8" and 5 1/2" inch Composite Drill Pipe. Composite tube design has been completed and successfully tested for both the 3 3/8" and 5 1/2" CDP. The MCI design has been completed and successfully tested for the 3 3/8 inch CDP.

Full scale, 10' sections of the 5 ½" CDP have been tested with various iterations of the MCI design. Results have been mixed, but the latest iteration shows much promise and a final tweaking of the geometry is underway. This final design is expected to consistently exceed all specification requirements. Full length tests will be conducted next quarter.

Abrasion and erosion protection for the CDP will be provided.

1.) Internally by a layer of fiber glass in a polymeric matrix.
2.) Externally by an overall, replaceable abrasion coating and by "industry standard" centralizers.

The 3-3/8 inch drill pipe is scheduled to be used and field tested early October 2002 for short radius well drilling with mud and air.

All test specimen fabrication and initial manufacturing will be at ACPT. All facets of the pilot plant are either operational or in the process of being brought on stream. Some details of the specific fabrication processes are still under development.

Design and Analysis is a continuous effort which will continue throughout the DOE contract and then will be an intimate part of all ongoing CDP manufacturing operations. Initial work concentrated on specifying the requirements for a "typical" drill pipe which when converted to the capabilities of composites would enable extended reach and "deeper" water drilling. These requirements have continually been refined during this program and will be constantly upgraded as more experience in the use and manufacture of CDP are obtained. It will always be our goal to further extended the reach for horizontal drilling and enable drilling into even deeper water.

2.0 Experimental

Cost Effective Composite Drill Pipe (CDP)

NETL Cooperative Agreement DE-FC26-99FT40262

NETL

Morgantown, WV

by

ACPT, Inc.

Huntington Beach, CA

1 Aug 2002

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ACPT & DOE/NETL Short Radius, Extended Reach, Deep Water CDP

- **Introduction**
- **Summary**
  - **P.R./Tech Papers**
  - **Offshore Technology Conference**
- **Updates**
  - **Test Results**
  - **Short Radius**
  - **Manufacturing**
- **Tasks to Completion**
- **Follow-on Proposal**

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2.1. Concurrent Development

Concurrent Development Efforts

- 4 1/2 ID Pipe for Deep Water Extended Reach
  - Omsco, Steve Williamson - Partner
- 1 5/8 ID Pipe for Short Radius/Horizontal Drilling
  - Terra Drilling - Field Evaluation
  - Grand Resources - Field Evaluation
- Substantial Progress since last DOE visit
  - Prior efforts summarized
  - New developments to be presented

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2.2. Configuration Development

Configuration Development

- **Baseline Deep Well Pipe**
  - **4 1/4 ID x 7 Tool Joint OD x 30 Ft**
    - **Configuration based on Grant-Prideco Input**
    - **Load, Torque, Pressure, Temperature Requirements Developed**
- **Development, Design and Testing of 1/3rd Scale**
  - **Pressure scales by 1, Load scales by 9, Torque scales by 27**
  - **Progression of material, ply schedules and fitting interface designs**
  - **Final scale test configuration meets requirements**
- **Omsco Analyzes 3 Drilling Scenarios**
  - **4 1/4 pipe is hydraulically challenged**
  - **New load, torque, pressure requirements developed (relaxed)**

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Configuration Development

- **Full size (4 1/4 ID) Testing - 10 feet length**
  - **Five Tension Tests - Failure load less than required, including 1.25 Safety Factor**
  - **Two Torsion Tests - Failure Torque less than required**
- **Terra Drilling - Short Radius Drilling**
  - **Requirements developed through Omsco**
  - **Design configuration is based upon 1/3rd scale testing**
    - **More robust interface fitting developed**
    - **5 Short Length and 2 full length specimens tested to failure**
    - **All requirements are exceeded**
- **Omsco requires 4 1/2 ID pipe as minimum**

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Configuration Development

- **New Baseline: 4-1/2 ID x 7 OD Pipe**
  - **Developed and Employed improved MCI**
  - **Current Tests: Axial Load exceeds requirements**
    - **544,500 lbf attained versus 450,000 lbf specified**
- **Omsco Requests 4 3/4 ID Pipe be developed**
  - **Better Hydraulics**
  - **Increases Reach Capability**
  - **Requires Manufacturing Technology Development**
- **Delivery of Terra Joints to Oman**
  - **Additional Joints to OK and/or TX by August 2nd**
- **Delivery of 5 Joints to Grand Resources**
  - **Additional Joints by August 9th**

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2.3. Field Testing

Field Test Data Requested

REQUESTED DATA	MEASUREMENT	INFORMATION
Max-Min-Operating Torque	Drive Motor Current Draw	Operating vs. Specification
Max-Min-Operating Tension Load	Drive Motor Load Cell	Operating vs. Specification
Max-Min-Operating Pressure	Drill Head Sensor	Operating vs. Specification
Max-Min-Operating Compression Load	Drive Motor Load Cell	Operating vs. Specification
Max-Min-Operating Temperature	Drill Head Sensor	Operating vs. Specification
Shockloading/Hammering	Drill Operator Records	Operating Environment
Torque Windup	Drill Operator Records	Stiffness Specification
Geologic Formation	Observation	Toughness vs. Wear
Drill Mud or Other Fluid Used	Drill Operator Records	Internal Erosion
External Coating Wear	Observation	External Errosion
External Abrasion	Observation	Centralizer Effectiveness
Location of CDP in Drill String	Drill Operator Records	Parametric Data
Minimum Radius of Curvature	Drill Operator Records	Bending vs. Tension Loads
Downwell Gases/Fluids/Chemicals	Mud Sampling	Chemical Resistance
General Performance	Observation	Product Improvement
Before/After Drilling Photos	Digital Camera	Permanent Record

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Terra Development and Status

- **Final Specification and Requirements**
  - **25,000 lbf Tension Rating, > 75,000 lbf Failure**
  - **2,000 ft-lb Torsion Rating, > 6,000 ft-lb Failure**
  - **±1,000 psi Pressure Rating, >2,000 psi Burst**
  - **325°F Service Temperature**
  - **1 5/8 ID, 2 1/2 OD, 3 3/8 Pin/Box OD, NC 26 Thread (modified)**
- **Final Configuration Developed - Dwg. No. 3075**
  - **7 Short Length Pipes Tested**
  - **2 Full Length Pipes Tested**
    - **Tension, Torsion and Pressure**
    - **All Requirements Exceeded**

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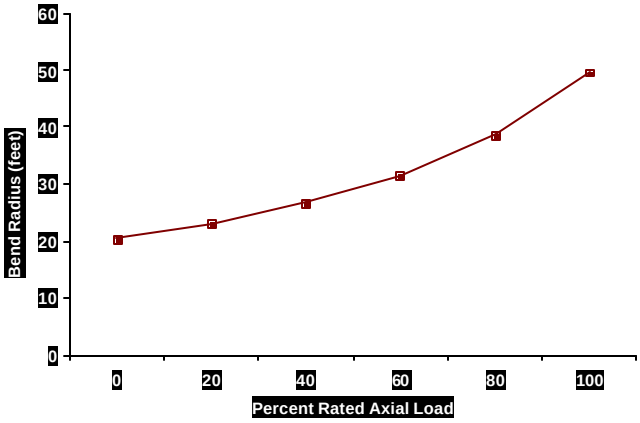
3 3/8 ID Pipe Allowable Bend Radius vs. % Rated Load



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3.0 Results and Discussion

3.1. Design, Testing, Product Ratings

13 Design Configurations Investigated

- **Tapered Wave Thread**
- **Tapered Wave Grooves**
- **Spiral Wave Groove**
- **Tapered Barbed Hose**
- **Trapped Recess**

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Testing Performed Since Last Report

TEST ID	DATE	INITIAL FAILURE LOAD	DESCRIPTION
28	10/1/2001	91,750	Terra #1 Short
29	10/9/2001	86,424	Terra #2 Short
30	10/12/2001	76,007	Terra #3 Short
31	11/15/2001	72,119	Terra #4 Short
32	11/15/2001	71,173	Terra #5 Short
33	5/21/2002	75,594	Terra #6 Short
34	6/5/2002	80,660	Terra #7 Short
Torsion Tests			
1	11/9/2001	> 5714 Ft-Lb	Terra #8 Short
2	5/15/2002	> 6000 Ft-Lb	Terra #9 Short
Full Length Tests			
27	8/17/2001	398,600	4 1/4 Pipe x 10 Ft
35	3/11/2002	124,850	Terra #10 30' Long
36	6/5/2002	544,500	4 1/2 Pipe x 10 Ft
37	6/5/2002	423,000	4 1/2 Pipe x 10 Ft
38	6/21/2002	113,855	Terra #11 30' Long

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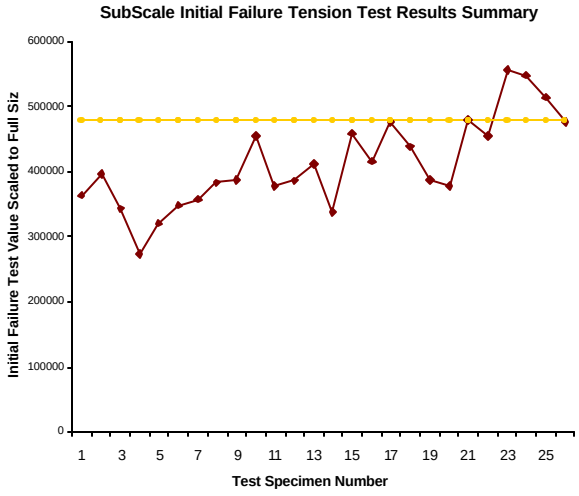
Test Specimens Scaled to 4 1/4 ID Pipe



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Product Data Sheet
Extended Reach/Deep Water

Mechanical Specifications

Bending Stiffness	EI	180. x10^6 lb-in^2
Torsional Stiffness	GJ	115. x10^6 lb-in^2
Axial Stiffness	EA	33.4 x10^6 lb
Rated Tension Load	P	450,000 lb
Rated Torsion Load	T	25,000 ft-lb
Rated Compression Load	P_c	250,000 lb
Rated Internal Pressure	P_i	9,500 psi
Maximum Service Temperature	F	325°F

Design Specifications

Tube Inside Diameter	ID	4 1/2 in
Tube Outside Diameter	OD	5 1/2 in
Length (Pin-to-Box)	L	360 in (30 ft)
Centralizers	-	5 eq. Spaced
Weight	LB	375 lb.

Connection Specifications

Pin/Box Diameter	OD	7 in
Bore	ID	4 1/2 in
Thread	IF	Customer Spec.

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Short Radius Drilling
Product Data Sheet

Bending Stiffness	**EI**	**7.22 x106 lb-in2**
Torsional Stiffness	**GJ**	**11.30 x106 lb-in2**
Axial Stiffness	**AE**	**14.30 x106 lb**
Rated Tension Load	**P**	**25,000 lb**
Rated Torsion Load	**T**	**2,000 ft-lb**
Rated Compression Load	**Pc**	**50,000 lb**
Rated Internal Pressure	**Pi**	**1,000 psi**
Maximum Service Temperature	**F**	**325°F**
Design Specifications		
Tube Inside Diameter	**ID**	**1 5/8 in**
Tube Outside Diameter	**OD**	**2 1/2 in**
Length (Pin-to-Box)	**L**	**360 in (30 ft)**
Centralizers	**-**	**5 eq. Spaced**
Weight	**LB**	**92 Pounds**
Connection Specifications		
Pin/Box Diameter	**OD**	**3 3/8 in**
Bore	**ID**	**1 5/8 in**
Thread	**IF**	**NC26 modified**

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Summary

- **Extended Reach/Deep Water & Short Radius Concurrent Development Effort**
- **Short Radius Pipe in Field Trials by October**
- **4 1/2” ID ER/DW pipe is hydraulically challenged**
- **Proprietary, improved MCI design required for maximum load capability**
- **Field Tests for ER/DW in Spring 2003**

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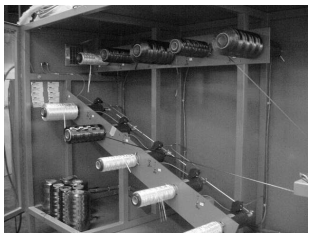
3.2. Manufacturing Process Development

Manufacturing Process

- Steel tool joints
  - Machine
  - Bond prep
- Filament Wind
  - Preparation/Set-Up
  - Resin mix/batch
  - Wind pipe



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Manufacturing Process

- Oven Cure
- Mandrel Extraction

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Manufacturing Process

- Machine composite to match tool joint OD

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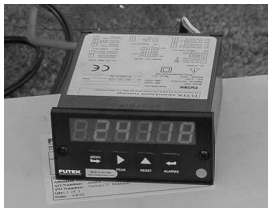
Manufacturing Process

- Proof testing



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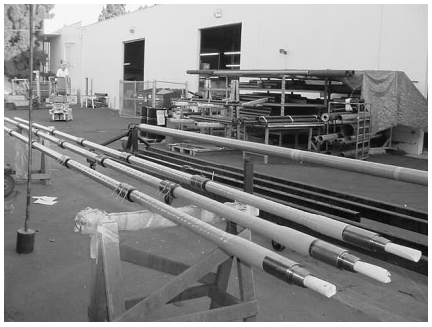
Manufacturing Process

- Abrasion Resistant Coating
- Bond on centralizers
- Final QC, serialization
- Pack and ship



Shipped to Grand Resources July 26th

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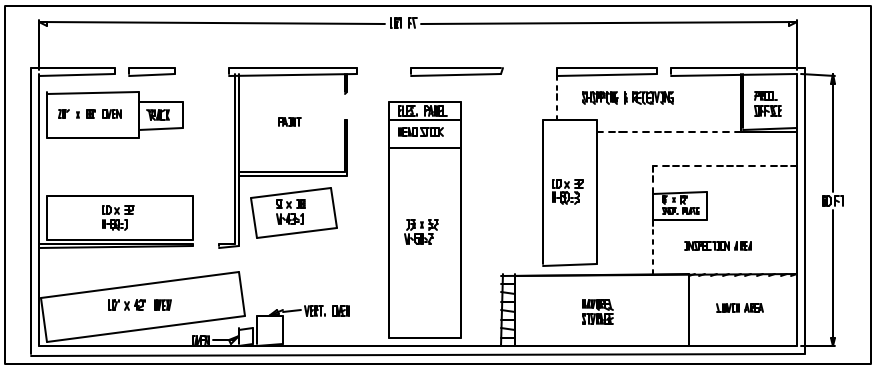
Manufacturing

- Pilot Plant Operations
  - Process Optimization
  - Continual Improvement



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4.0 Other Discussion

4.1. Public Relations

Summary– Public Relations

- Symposium Presentations/Publications
  - SPE/IADC: The Netherlands, March, 2001
  - OTC, Houston, May, 2002
  - GTI: Orlando, September, 2002
- Publications
  - Gas Tips, Volume 8, Number 1, Winter 2001
  - Composites in Offshore Oil, Spring 2002
  - www.petroalert.info, Summer 2002
- Industry Trade Shows
  - OTC, DOE/NETL Booth, 2000
  - OTC, DOE/NETL Booth, 2001
  - OTC, DOE/NETL Booth, 2002
  - SAMPE Symposium, Long Beach, April, 2002

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Summary– Public Relations

- Industry Reviews
  - Houston: Quarterly Review, by Invitation
    - 11/04/99, 02/22/00, 05/04/99
  - Congressman Dana Rohrbacher
    - Personal Briefing, 06/06/00
  - ANACONDA
    - Briefing to Halliburton management, 06/06/00
  - SIG Conference
    - Presentation, 06/22/00
  - SEAC Conference
    - Presentation, 10/31/00

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4.2. Offshore Technology Conference

Offshore Technology Conference

Development and Manufacture of Cost Effective Composite Drill Pipe

Program Sponsor: U.S. Department of Energy
National Energy Technology Laboratory
Contract No: DE-FC26-99FT4062
SPE Paper 14266

Authored and Presented By:
Dr. James C. Leslie, CEO
ACPT, Inc., Huntington Beach, CA

- **Extend Horizontal Reach**
- **Improve LWD and MWD**
- **Provide Enabling Technology and Cost Savings in Deep Water Drilling**

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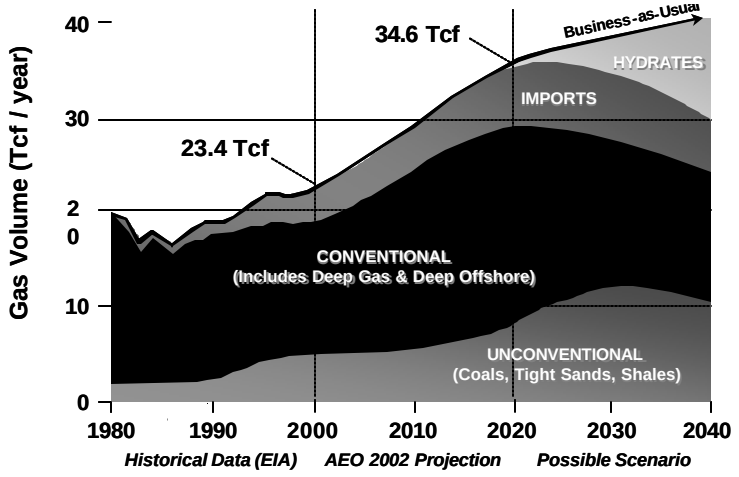
Gas Needed to Meet Demand



Sources: NETL, Boswell

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Advantages of Composite Drill Pipe

- Enabling Technology
- Light Weight
  - ½ that of Steel
- Fatigue Resistant
  - Flexible
- Tailorable
- Repairable
- Signal / Power - in Walls

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Program Status

- Specifications Complete
- Small Scale Testing Complete
- Composite Tube / Metal Fitting
- Pilot Plant in Process
- 3 3/8” Short Radius
- Full Size: Omsco

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Specifications: Current Designs

	7 in.	3-3/8 in.
Tensile Strength, ksi	450	25
Compressive Strength, ksi	250	50
Temperature, F	325	325
Internal Pressure, ksi	9.5	1
External Pressure, ksi	6.5	1
Torque, lb-ft	25k	2k

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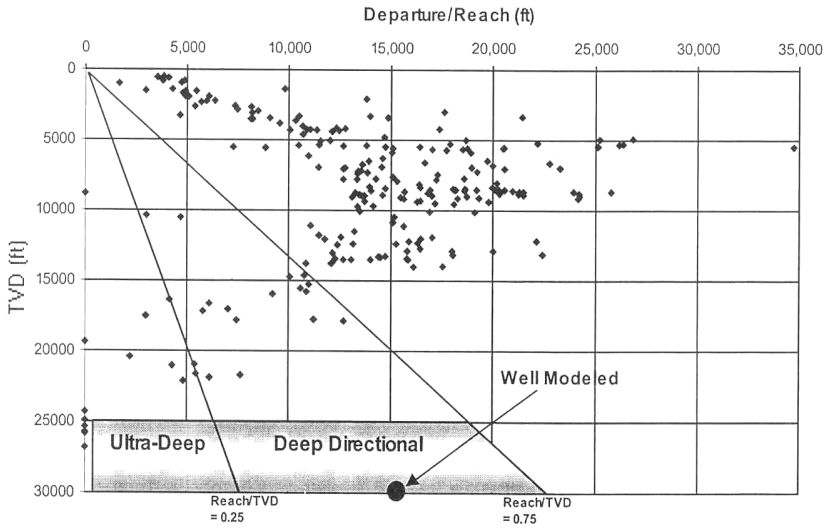

Figure 1 – Industry ER, UD, and DDD Activity

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Strength-to-Weight Ratios

Drill Pipe Material	30 ft Section	45 ft Section
Std 135 Steel	480,000	
Titanium	750,000	
5-5/16 CDP	625,000	1,011,000
3-3/8 CDP (2K Torque)	700,000	780,000
3-3/8 CDP (1K Torque)	1,430,000	1,610,000

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Cost / Value

- **Enabling Technology**
- **Weight Reduction**
  - **Platform**
  - **Transportation**
  - **Torque Equipment**

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Cost / Value

- **Direct Comparison**
  - **3 to 5 Steel**
  - **Tailor CDP**
  - **Extra Cost**
  - **Steel at Limit**
- **Signal / Power Transmission**

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Winding Composite Drill Pipe

Computer Controlled Filament Winding

Tailorable Properties

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Testing

- Materials
- 1/3 Scale
- 10 ft Full Size
- Full Size
- Down Well

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Materials Testing

- Basic Properties
- Down Well Exposure
- Wear Abrasion

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Abrasion Resistant Coating

Comparative Mass Loss

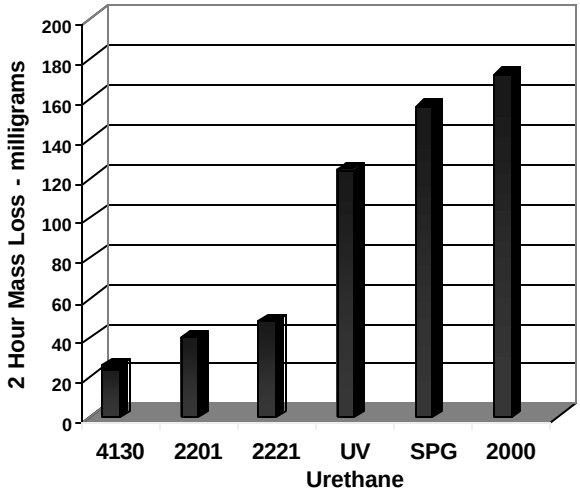

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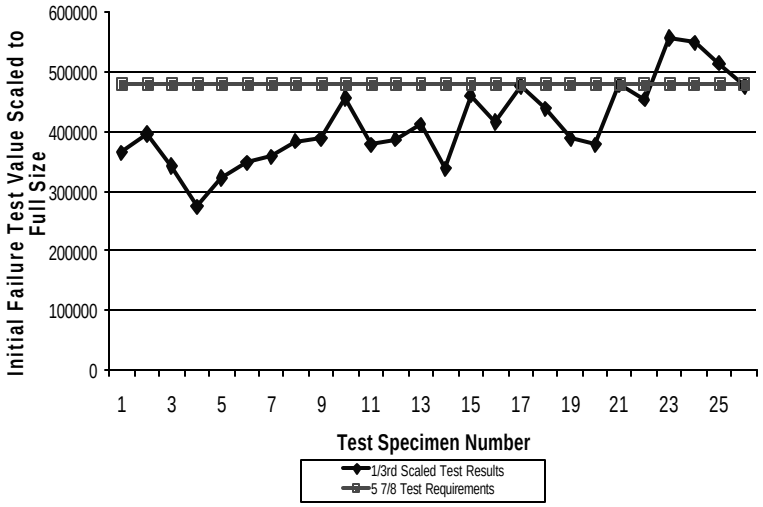
Figure 4: One Third Scale Tension Test Summary



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10 Ft - Full Diameter
Tension Test

TESTING COMPLIMENTS OF VARCO

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10Ft-Full Diameter
Torsion Test

Testing Compliments of VARCO Systems

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LWD / MWD Status

- **Thru Pipe Wall: OK**
- **Steel Joint**
  - **Direct Connect**
  - **Acoustic Transmission**
  - **Inductive Transmission**

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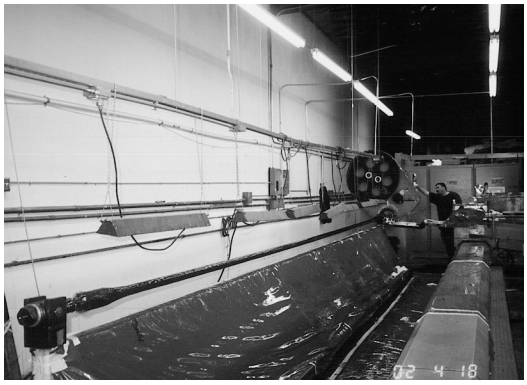
Manufacturing

- **Pilot Plant: ACPT**
  - **30 ft – 3 3/8 inch C.D.P.**
  - **30 ft – 5 7/8 inch C.D.P.**
- **Full Scale: Omsco**
  - **As / When Needed**



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Summary

- **Enabling Technology**
- **Cost Effective**
- **Signal / Power Transmission**
- **3 3/8” Short Radius CDP : NOW**
- **5 7/8” :Spring of 2003**

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5.0 Conclusions

Commercialization

- **Field Tests**
  - **Acceptable field experience**
- **Proof Tests**
  - **Complete OMSCO test plan**
- **Patents**
  - **Intellectual property rights**
  - **Commercial Partners desire ROI**
- **Marketing/Sales**
  - **Short Radius**
  - **Extended Reach/Deep Water**

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Tasks for Completion by April 30, 2003

- **Short Radius**
  - **Preliminary field test results by end of 2002**
  - **Improve mfg process**
  - **Pilot plant ramp up**
  - **Commercialize**
- **ER/DW**
  - **Improve process flow and handling**
    - **Full length CDP and mandrel weighs @1500 lbs**
  - **Complete battery of test by end of 2002**
  - **Solicit and secure field test partner**
  - **Pilot plant ramp up**
  - **Commercialize**

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6.0 References

1. Leslie, Dr. J.C. ; Jean, J ; Truong, L ; Neubert, H ; and Leslie, J. II.; "Development and Manufacture of Cost Effective Composite Drill Pipe"; SPE Paper No. 14266; SPE 2002 Conference.
2. Leslie, Dr. J.C. ; Jean, J ; Truong, L ; and Neubert, H : Development and Manufacture of Cost Effective Composite Drill Pipe, Quarterly Progress Report, ACPT, Huntington Beach, CA January 2000.